

**INTRODUCTION TO
WGAssociates
and
SOLAR DISH/STIRLING
POWER SYSTEMS**



WGAssociates

**11020 AUDELIA RD
SUITE B106**

DALLAS TEXAS 75243

PHONE 214-221-2273

FAX 214-221-4266

EMAIL wgassociates@swbell.net

WGAssociates Product Description

1. INTRODUCTION

WGAssociates (WGA) is a small company incorporated in Texas as Wilkinson, Goldberg, and Associates, Inc. It was formed in 1983 to provide engineering services to government and to industry. From its inception WGA has been extensively engaged in the design and construction of solar concentrators with their attendant control systems, in both the thermal and photovoltaic arenas. As examples, WGA engineers designed two Test Bed Concentrators (11 Meter diameter dish solar collectors), as shown in Figure 1. These have been operating at Sandia for almost 20 years. The 25 kW_e faceted Stretched-Membrane Concentrator shown in Figure 2, was also designed and built for Sandia as part of their dish/Stirling program.



Figure 1 Test Bed Concentrator

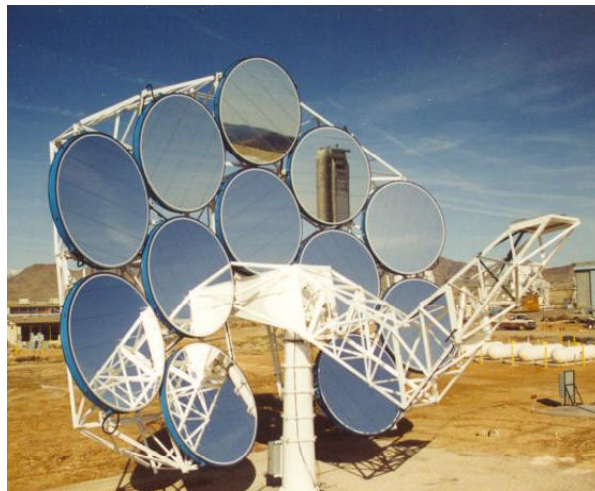


Figure 2 Stretched-Membrane Concentrator

WGA designed and fabricated the high performance 25 kW_e glass-metal mirrored dish/Stirling concentrator for Cummins Power Generation (CPG) shown in Figure 3 with an Aisin Stirling Cycle engine installed. Recently, WGA completed design, fabrication, and installation of the WGA-500, a 10 kW_e glass-mirror surfaced dish/Stirling system for use in on-grid applications. This system, shown in Figure 4 was installed, tested, and is presently operating at Sandia Albuquerque. This design is presently being adapted for remote off-grid applications.



Figure 3 WGA-1500 25 kW_e Concentrator



Figure 4 WGA-500 10kW_e Collector

WGAssociates personnel are experienced in the design and construction of various types of antenna structures and control systems, including satellite communications, tropospheric scatter, radar, and radio telescopes up to 91 m (300 ft) in diameter. These structures were, for the most part, efficient, high strength-to-weight ratio space frames designed to meet exacting performance requirements under high wind loads and other adverse environmental conditions. The wealth of experience gained in the development of such antenna technology was, and is, directly transferable to the development of solar concentrators.

2. SOLAR COLLECTOR PRODUCTS

Currently WGAssociates has three principal Solar Collector products. These are:

1. A parabolic dish solar concentrator system, Model No. WGA-500, sized to produce 10 to 15 kW_e of electrical power.
2. A parabolic dish solar concentrator system, Model No. WGA-1500, for electrical power production in the range of 30 to 45 kW_e.
3. Collector control systems, Model No. WGA-CCS, for control and monitoring of solar collector systems.

Significant characteristics of these products are described in Section 3.

The Model WGA-1500 concentrator design is based on the earlier 25 kW_e concentrators designed and built by WGA in 1995 and successfully tested by CPG. The structure design has been upgraded to reduce weight and cost. It has been successfully subjected to finite element analysis. The reflector panel fabrication methods have been considerably refined and made more cost effective. Samples made with the new fabrication methods have been tested both before and after accelerated life testing by Sandia National Laboratories with excellent results (end of life slope errors less than 1.5 milliradians). The CPG dish delivered 94% or the reflected energy into a focal plane aperture of 13 inches (0.33 meters) diameter as shown in Figure 5.

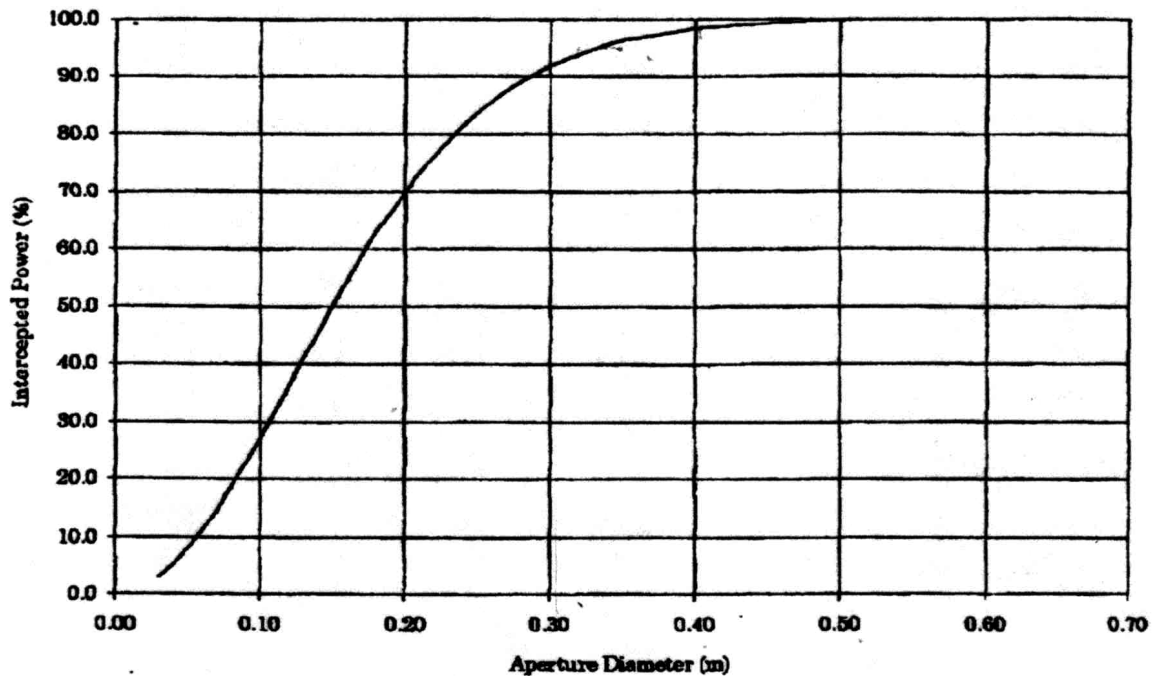


Figure 5 Power Intercept for the WGA-1500 Concentrator

The Model WGA-1500 concentrator is compatible with a number of existing Power Conversion Systems (PCS) including the Stirling Thermal Motors STM 4-120 Stirling Engine, United Stirling Motors USAB 4-95 Stirling Engine, and the Allied Signal Brayton Cycle Engine. All of these PCS's are capable of operating in a hybrid mode using solar energy when available or burning some form of fossil fuel or bio-gas in periods of no sun.

The design of the Model WGA-500 concentrator currently operating at Sandia is being upgraded for increased cost effectiveness and fabrication of two additional systems is currently under contract. The Model WGA-500 is designed for integration with the Schlaich Bergemann und Partner SOLO 161 Stirling Cycle PCS. The concentrator is, however, readily adaptable to other PCS units. The concentrator has demonstrated a high stiffness-to-weight ratio. The improved second generation mirror panels, as tested by the National Renewable Energy Laboratories (NREL), have a proven 1 milliradian RMS slope Error. As a result, the concentrator has extreme optical accuracy, delivering 100% of the reflected energy from the dish into a 6 inch diameter focal plane aperture (see Figure 6).

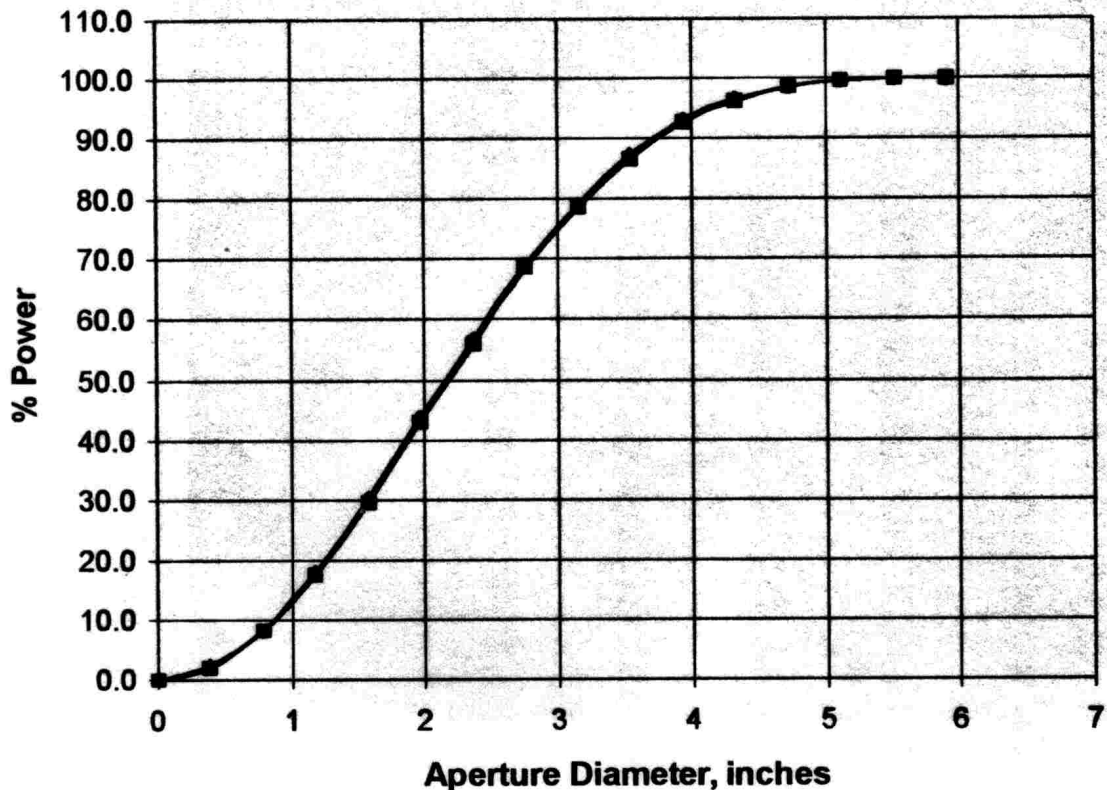


Figure 6 Power Intercept for the WGA-500 Concentrator

The WGA-CCS control system is an advanced design of a system that has operated successfully for some 15 years. It is a fully integrated system that includes off-the-shelf hardware operating with custom software, providing control and monitoring of a concentrator and a power conversion system. It provides unattended operation with automatic start-up, sun acquisition, sun tracking, shutdown, fail safe fault monitoring and response, etc. It provides tracking accuracy within 1 milliradian, rms. The system is described in greater detail below.

3. COLLECTOR FEATURES

The WGA dish/Stirling Collector Systems comprises three major sub-systems - the Concentrator System, the Power Conversion System (PCS), and the Collector Control System (CCS).

3.1. CONCENTRATORS

The WGA-1500 30 kW_e (nominal) concentrator is a second generation version of the successful 25 kW_e dish concentrator shown in Figure 3 above, originally designed and constructed for Cummins Power Generation, a division of Cummins Engine, Inc. The WGA-500, a 10 kW_e (nominal) concentrator, shown in Figure 4 above, employs similar technology to that used in the WGA-1500.

Both concentrators are paraboloidal point-focusing, full tracking dish concentrators in an elevation-over-azimuth axis arrangement. The concentrator designs are configured to meet the requirements of the commercial marketplace, in both power grid connected and remote (off-grid) applications.

Each concentrator consists of five major subassemblies - the tracking structure, the reflector surface, the base structure, the azimuth drive and the elevation drive.

The tracking structure for support of the reflector surface is a fully triangulated space frame constructed primarily of structurally efficient thin wall tubing. Virtually all joints are pinned to eliminate bending moments. The resulting assembly is lightweight and exhibits an extremely high stiffness-to-weight ratio.

In each concentrator, the dish is surfaced with an array of glass-metal composite mirror panels. Each panel consists of a 1-mm silver/glass mirror laminated to a thin-gage steel sheet, which is backed by a lightweight structural core and another thin steel sheet. The "sandwich" is fully bonded with structural adhesives. The completed panels exhibit extraordinarily low slope errors and high structural stability. The mirror panels, when installed on the tracking structure, are fully adjustable for alignment purposes.

The base structure, or pedestal, is made from standard pipe with welded flanges at both ends for integration with the foundation and the azimuth drive, respectively.

The tracking drives are sized to fit the specific load conditions for each concentrator. In each case the azimuth drive trains use a commercial, field-proven, planocentric gear reducer with a ratio of approximately 16,000:1. The elevation drive trains employ off-the-shelf ball screw linear actuators. The 10 kW concentrator is configured to allow the dish to depress in elevation to 25 degrees below horizontal for engine maintenance convenience. This option can be included readily in the 30 kW dish.

Optical performance of these concentrators is significantly better than is possible with present stretched membrane reflectors. The WGA systems yield an intercept factor of better than 95%, leading to a net thermal efficiency of at least 89%. The concentrator design lends itself to low cost, conventional fabrication and installation processes.

The salient characteristics of the concentrators are shown below.

3.1.1 WGA-1500 CONCENTRATOR CHARACTERISTICS

Aperture Diameter	15.6 m (51.2 ft)
Focal Length	9.37 m (369 in)
Focal Ratio, f/d	0.6
Rim Angle	45°
Projected Area (Aperture)	140 m ² (1510 ft ²)
Peak Concentration Ratio	>5000:1 at 1000 W/m ² insolation
Reflector Surface Contour	Paraboloidal per $Y^2 = 4fZ$
Facet Construction	1-mm silvered glass mirrors bonded to a composite substrate of two thin steel sheets separated by a lightweight structural core
Reflectivity	94%
Slope Error	1.5 mrad, rms
Mirror Support Structure	Thin-wall tubular space frame
Tracking Axis Configuration	Elevation over Azimuth
Pedestal Configuration	Standard pipe, flanged both ends
Slew Rates	38 deg/min, each axis
Weight (less Engine)	
• On Elevation Axis	6,071 kg (13,357 lbs)
• Pedestal & Az Drive	1,727 kg (3,800 lbs)
Design Focal Point Load	909 kg (2,000 lbs)
Wind	
• Operating	15.6 m/sec (35 mph)
• Drive to Stow (Any dish Attitude)	24.6 m/sec (55 mph)
• Stow	40.2 m/sec (90 mph)
Thermal Output	123.8 kW _t at 1000W/m ² insolation
Optical Efficiency	89%

3.1.2 WGA-500 CONCENTRATOR CHARACTERISTICS

Aperture Diameter	8.7 m (28.5 ft)
Focal Length	5.33 m (209.83 in)
Focal Ratio, f/d	0.6
Rim Angle	45°
Projected Area (Aperture)	43.5 m ² (468 ft ²)
Peak Concentration Ratio	>11,000:1 at 1000 W/m ² insolation
Reflector Surface Contour	Paraboloidal per $Y^2 = 4fZ$
Facet Construction	1-mm silvered glass mirrors bonded to a composite substrate of two thin steel sheets separated by a lightweight structural core
Reflectivity	94%
Slope Error	1.0 milliradian, rms
Mirror Support Structure	Thin-wall tubular space frame
Tracking Axis Configuration	Elevation over Azimuth
Pedestal Configuration	Standard pipe, flanged both ends
Slew Rates	38 deg/min, each axis
Weight (less Engine)	
• On Elevation Axis	1675 kg (3,686 lbs)
• Pedestal & Az Drive	546 kg (1,200 lbs)
Max Focal Point Load	546 kg (1,200 lbs)
Wind	
• Operating	15.6 m/sec (35 mph)
• Drive to Stow (Any dish Attitude)	24.6 m/sec (55 mph)
• Stow	40.2 m/sec (90 mph)
Thermal Output	41 kW _t at 1000W/m ² insolation
Optical Efficiency	89%

3.2 - WGA-CCS COLLECTOR CONTROL SYSTEM

The WGA-CCS Collector Control System provides control and monitoring of a Concentrator and a Power Conversion System (receiver/engine/generator). It can also provide a power grid interface. Each Collector System possesses the intelligence for all aspects of normal operation, with a network data link used only for supervisory monitoring and control. It provides for unattended collector operation with automatic startup and shutdown. Sun tracking uses a hybrid approach consisting of both passive and active tracking. The use of active tracking allows for automated structural alignment error detection and correction and automated clock drift correction, while passive (program) tracking allows tracking of the sun during periods of cloud cover.

There are control system versions available for both power grid applications and for remote off-grid applications.

The control system uses an off-the-shelf industrial grade embedded PC single board computer and I/O cards. The software is written in the C++ language. Software is developed and debugged on a PC using standard PC based compilers and debuggers. The software can be readily adapted for different system configurations and to run with another vendor's embedded PC and/or I/O cards as hardware availability changes. The present C++ software has amassed over a hundred thousand hours of operation on solar collectors with great success.

A summary of significant characteristics of the WGA-CCS Collector Control System follows.

3.2.1 WGA-CCS COLLECTOR CONTROL SYSTEM FEATURES

Unattended operation:

- Automatic start-up, sun acquisition, and both passive and active sun tracking.
- Automatic control and monitoring of the engine/generator or the engine/generator controller.
- Automatic control of the power grid interface.
- Automatic stowing with excessive wind speed and/or end of day.
- Automatic escape from the sun when insufficient insolation exists and/or when automatically detected fault conditions (including power grid failure) exist.
- Automatic shutter, brake, alternative fuel control for collector systems so equipped.
- Automatic alignment error correction and controller clock drift correction.
- Automatic recovery from grid power failure or power down mode.
- Automatic performance data collection with download on-command.

Fully integrated, standalone control system:

- Integrated Control System concept features control cabinets located at each dish that connect to all sensors and actuators on that dish.
- Integrated engine/generator interface maximizes system performance.
- Integrated performance data acquisition enables recording of valuable operating data.

Well proven, fully automatic dish tracking control:

- Closed loop capture range of 10 to 20 milliradians allows for lower cost structures and structural alignment methods compared to traditional open loop tracking methods.
- Hybrid tracking methodology - clock time based calculations that determine the current location of the sun, with adjustments then being made to that position by the active sun tracking algorithms (closed loop tracking). Closed loop tracking is based on either Flux Tracking or on Insolation Tracking (User's choice).
- Tracking accuracy is better than 1.0 milliradian, rms, with a WGA concentrator.
- Automated Self-Alignment uses tracking error analysis to measure and correct for all critical dish mounting alignment errors and clock time errors to insure calculated positioning stays within the closed loop capture range.
- Automatic fault monitoring and controlling an appropriate response.
- Readily adapted to any concentrator axis system (Az/El, Polar, Roll/Tilt, etc.) with capability for major deviations from normal coordinates. For example, a polar mount designed for 45° latitude can be used effectively at 30° latitude.

Built in monitoring and control:

- Monitoring and control capability provided remotely via dial-up modem, the Internet, and a local network connected to a PC.
- Local monitoring capability provided by a hand held input and display unit.
- Remote downloading of system software into nonvolatile Flash EPROM memory.
- Networking allows sharing of sensors such as high wind speed sensors in a multiple unit field or solar farm application.

User friendly interfaces:

- Menu driven handheld terminal control and monitoring.
- Command line driven mode for extensive technician diagnostics.
- DOS and WINDOWS based PC remote user interfaces.

Hardware Implementation:

- Contained in a weather-proof enclosure to be installed at the concentrator.
- Operates on either 50 or 60 Hz.
- Optional transformer to match engine/generator output voltage to power grid voltage.
- Utilizes off-the-shelf, industrial temperature range components.
- Computer with both digital and analog I/O is an embedded PC compatible platform with a PC/104 bus for expansion capability.
- Concentrator Axis Drive Motors may be either AC or DC.
- Position Sensors - Solid state Hall Effect sensors are magnetically actuated.
- Flux Tracking Sensors, if used - Four high temperature thermocouples (1/4" dia., Type K or N) mounted around the engine receiver aperture.
- Insolation Tracking, if used - photovoltaic cells in a shadow box mounted on the concentrator structure.